Designing a Low Cost Bedside Workstation for Intensive Care Units

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The paper describes the design and implementation of a software architecture for a low cost bedside workstation for intensive care units. The development is fully integrated into the information infrastructure of the existing hospital information system (HIS) at the University Hospital of Gießen. It provides cost efficient and reliable access for data entry and review from the HIS database from within patient rooms, even in very space limited environments. The architecture further supports automatical data input from medical devices. First results from three different intensive care units are reported.

INTRODUCTION

At the University Hospital of Gießen, a 1300 bed hospital within the middle of Germany, a fully functional hospital information system (HIS) is under continous development since 1989 /1/. While this HIS is now in routine use on more than 100 wards and outpatient clinics, its functionality is limited until today to the more administrative tasks of physicians and nurses daily work like diagnoses and procedure coding, discharge summary writing etc.. The main goal of the here described work was to add more clinical information to the HIS database. Therefore it started in an environment where the need for continous and detailed documentation is naturally very high - the Intensive Care Units (ICU). In 1993 a design group consisting of nurses and medical informatics people was founded which continually supports the development process. The goal was to develop a medical workstation architecture, which allows for data entry and review within a patients room, even within space limited environments. A central requirement was the low cost paradigma, because of limited financial resources in nearly all clinical departments. The development should be a cost efficient alternative to commercially available ICU information systems like Care-Vue from Hewlett-Packard or EMTEK from EMTEK Corporation. Because the work started within a cardiology ICU, the first modules implemented were centered around the treatment of patients with cardiac diseases. The process has been extended to a neurosurgical ICU in 1995 and since 1996 for some areas by the department of anaestesiology. Parts of the software are used since october 1995 in a hospital wide project for documenting TISS-Scores on all ICUs which has been initiated by the head of the nursing department.

GENERAL REQUIREMENTS FOR THE BEDSIDE WORKSTATION

The general requirements which guided the development of the whole workstation software have been defined according to the experience with the routine operation of the existing HIS and the special requirements of a bedside workplace which have been gathered during the sessions with the future system users. They will now be listed according to their perceived importance for the success of the overall project.

Reliability, Availability and Performance. During the operation of the HIS we found that even the relatively small set of functions which is provided through the overall HIS must be available without any interruption. In a system which has the tendency to put a much higher amount of patient data onto the computer these requirements are even higher. Beneath the requirements of reliability and availability we found that system performance is a very crititical factor for the success of the project. We needed several adaptions to fullfil the user needs in this area.

Full HIS integration. Lot of the functions which are necessary within the ICU environment were available within the hospital wide HIS. Especially within the fields of patient management and laboratory results reporting a full integration of the bedside workstations was needed. On the other hand features that are primarily needed by the bedside systems like bed management could enrich the usability of the global HIS. Therefore it was decided to integrate the bedside machines as far as possible into the overall HIS architecture, even if that makes the development process somewhat slower and more difficult.

User Input centered design. After some early discussions with the potential end users it became clear, that even if the desired system should be able to automatically process data from medical devices a vast amount of data has to be entered primarily by the nurses who care for the patient. Therefore the user

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interface has to be designed to support data entry in a way that is choosen by the user and not by the system. As one result of this decision, the interface supports both mouse and key driven actions for nearly all functions. Also the development is not bound to available interface objects of the operating system; instead there have been special graphical objects designed that support the users needs in any way.

Design for planning and collaborative work. Even if a bedside workstation is a useful device for input and review of patient data, it could not be seen as the solution for all problems of ICU data processing. After a lot of discussions with the physicians and nurses of the test ward it became clear, that lot of the work could be done on a desktop PC in the physicians or nurses office on the ward. Therapy plans could be prepared on the central PC which are then confirmed or adapted on the bedside machine. Also nurses and physicians often act in a collaborative way which has to be supported by the software.

Data import from medical devices. Most of the ICUs today are equiped with medical devices that monitor a variety of biological parameters of the connected patients. Even if the role of automatic data input for the functionality of an ICU system is not so high as most people believe, the software should be prepared to process such data and handle these devices in a consistent way within its overall system architecture.

System Management. The introduction of bedside workstations increases the number of workstations in a noticeable way. It further makes a simple replacement strategy for defect hardware to a must. Therefore it seemed to be neccessary to both simplify installation and improve management capabilities of the HIS to continously service these machines.

REALIZATION

Hardware architecture

According to the paradigma of developing a low cost system, the development focused on cost effective PC systems for the bedside workplace. On the other hand, the goal of extending the data entry and review capabilities towards the representation of the common ICU paper flow charts required a fully functional graphical user interface (GUI). Software stability was another absolute requirement for the desired application field. From the existing standard PC operating systems that were available in 1992 when the development was started, the Apple Macintosh was selected because of its unique combination of a stable, easy to use and fully graphics oriented Operating system. Finally the Macintosh Power-Book portables were choosen as bedside machines because they add a very robust, small sized and battery buffered hardware to the above mentioned benefits of the Macintosh operating system. Such a system costs only the price which one has to pay for the equipment to mount the UNIX machines of an EMTEK installation on the wall of a patients room. In the final installation, the bedside machines are connected to the hospital wide Ethernet network which is now available within the patient rooms on the most ICUs in Gießen.

Software architecture

The software architecture could be subdivided into some basic concepts which will now be explained in more detail.

Single program multithreaded architecture. The before mentioned requirements combined with the inherent limits of PC based operating systems in handling multiple concurrent processes led to a software architecture consisting of a single program which is internally executing as a couple of multiple threads. These threads fall in three categories:

- user interface threads
  every open Program window is internally executed as an independent thread
- database interface threads
  two independent threads are executed against the host database server for continous and user driven data exchange between the host and the local database
- medical device interface threads
  one thread per connected medical device is responsible for importing and processing device data

For the successful implementation of such a concept it is essential to subdivide any program action into small parts, so that concurrent threads are able to execute. All io-actions must be executed in an asynchronous manner; otherwise they would block the interface.

Layered software architecture. The possible complications of the underlying multithreaded concept led to a layered software architecture where lot of the time critical functionality is concentrated in a database kernel machine. All user interface parts access the kernel only through interface functions. This limits unwanted side effects and allows for independent improvements of the kernel architecture.

Client Server architecture with local dataprocessing capabilities and central relational patient database. Within the central HIS the relational database technology has shown their benefits since 1990. It was decided to fully implement the database of the ICU system in relational technology, especially because existing

installations of ICU information systems have shown that there is an enormous need for statistical output which simply can be provided using a relational database management system (rdbms) and commercially available database tools.

The usage of a modern rdbms itself leads to a client server design. Besides this common technology the requirements of being autonomous for a limited amount of time and the need of high speed data preprocessing of connected medical devices leads to a concept where a patient oriented local database buffers all data on its way from the user to the central database. This decouples the performance characteristics of the frontend PC from that of the underlying rdbms.

Remote Procedure Call (rpc) concept for data storage and transfer. Before starting the work on the beside workstation a network interface for the HIS database has been successfully implemented which utilizes the concept of remote procedure calls for transferring complex data objects between the host database and a client machine /2/. These data objects often combine data from more than one table of the underlying rdbms. The tasks of denormalization or renormalization is performed by a database server process on the host. Based on this successful strategy the Bedside Workstation software exchanges such complex data objects between its local database and the database host. Within this concept the local database fulfills the task of patient specific storage of complex data objects. The local database can be optimized for patient specific data access without any normalization because it is never used for data analyzation purposes. This task is accomplished within the central rdbms using commercial tools. Access to the data of the local database is gained through special interface procedures after the data has been completely loaded into memory by the database kernel machine on the PC. The user interface programs control the data transfer through a set of interface procedures.

User interface objects library. To simplify the development of user interface programs within the choosen software architecture a standard program skeleton is provided which can be adapted for a special task. Furthermore a couple of standardized user interface objects is provided to unify the presentation of often needed interface objects like dictionary controlled choice lists, numerical and time entry fields and so on.

Applications

Using the basic software architecture, a set of workstation applications has been developed.

Access control and activity logging. Access to the system is protected by password and user-id. Further restrictions are provided by the known lokation of the machine. The mechanism is simultaneous to that implemented for the rest of the HIS. The user-id is stored along with the patient data during all data input.

Admission Discharge Trasnfer (ADT) applications. The applications of this categorie allow access to the administrative patient database of the hospital wide HIS. They provide basic information about the currently admitted patients, allow for admission, discharge and transfer of patients and provide the link between the bed lokation of a patient and the nearest bedside machine.

Graphical and Spreadsheet data display. After logging on to the system, user action is centered around either a graphical or spreadsheet like representation of the patient chart. The system automatically displays data for the patients that are linked to a specific bedside machine. It is possible to switch to any other patient of the ICU. From the patient chart display all other data input and review applications could be reached.

Vital signs, input-output. Applications for entering vital signs and input output information have been the first applications within the bedside workstation software. They fulfill basic needs within an ICU system especially because the integrated module for computing the input output balance frees the nurses from the burden of manually computing this information four times a day.

Nursing protocol. Beneath the documentation of vital signs most of the nursing documentation is free text. To standardize this documentation and nearby remove the need for repeated keying in of often needed terms a dictionary based application has been developed which allows for selection of terms from hierarchically ordered lists which come from the controlled vocabulary of the HIS. If a needed term is missing, the user can key in the needed information. The application further allows for the storage of nursing care plans which are represented by a series of nursing activities that could be stored with a single click into the database. They are later confirmed when the work is actually done. Figure 1 shows the user interface for the nursing protocol.

Medication ordering. Because of its inherit complexity the medication ordering module has been the last one within the development process. It is currently in a late prototype phase and looks much like the nursing protocol application.

Medical device connection. Since 1994, interfaces for three different medical devices have been added to the workstation software. The development started with a Propaq 140 multi function monitor from Protocol Systems Inc.. The import of 20 different parameters from that monitor combined with different types of data compression has been successfully tested /3/. Interfaces for a Nova bloodgas analyzer and the Siemens Sirecust series of Monitors have also been successfully tested. Unfortunately the only ward which has monitors that are equiped with serial interfaces is the ICU of the department of

anaesthesiology which owns a EMTEK ICU information system so there is no need for the bedside workstation software. The other ICUs are equiped with older monitor systems all without digital interfaces. Nevertheless the bedside workstation software is currently used in the anaestesiology department for automatical import of bloodgas data from a Nova analyzer. After reading the data from the analyzer the workstation forwards the results to the EMTEK system.

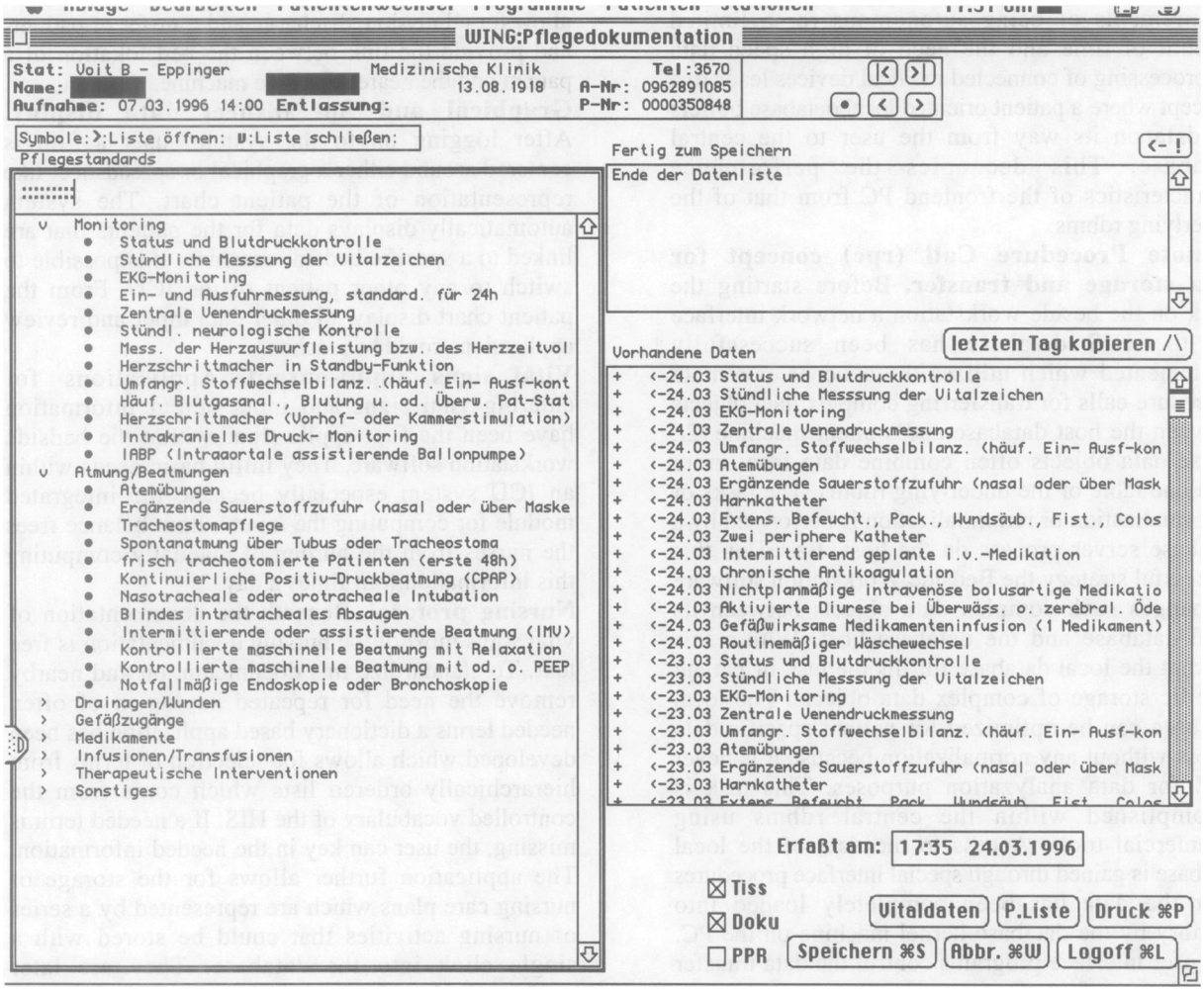

Figure 1: Sample screen from the nursing protocol application, showing two opened hierarchical pick lists and existing patient data

RESULTS

The development of the bedside workstation software was started in early 1993. Since June 1993 a design group consisting of nurses and medical informatics people is continously supporting the project. The first prototype was installed in early 1994 in a cardiology ICU. Since late 1994 this ward is equipped with Ethernet network in every patient room together with 10 Macintosh PowerBook 160 which run the bedside workstation software. In June 1995 the neurosurgery ICU also started documentation with three machines.

The first year of practical experience on the ICU showed that the concept of a small and cheap bedside workstation was feasible. In most of the ICUs the small PowerBooks are adopted by the personell because they are so nice little computers. Nevertheless the current limitations from the relatively small size of the PowerBook screen and its only gray scale display limit the usability of the complete software especially in the display of the graphical patient chart.

Since 1995 the surgical departments of the University Hospital of Gießen have been equiped with a Macintosh based surgical documentation system. This installation of nearly 400 PowerPCs

where the bedside workstation software acts as the only interface to the central HIS allowed the testing and verification of the database kernel functionality in a very large scale. The concept of local data storage showed its feasability and the central database servers could be optimized even for high workload. Lot of the user interface elements have been tested in a much wider area than expected at project start. In contrast to the bedside machines the PowerPCs are equiped with 17inch colour displays which supports especially the display of the graphical patient chart. Using this environment a documentation project has been started on all ICUs of the Gießen University Hospital in October 1995. Based on the nursing protocol application of the bedside workstation software which has been loaded with the definitions of the TISS (Therapeutic Intervention Scoring System) Scoring system a workload study has been conducted for all ICUs. The aquired data is analyzed with commercial tools using the data from the central rdbms. The study will finish in May 1996. Until now the project has shown a high degree of user acceptance for the choosen interface design within that central module. 150.000 records have been entered into the database using the nursing documentation module since project start. As a result, the head of the nursing department now supports the further development of the Bedside Workstation Project.

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References

1. Prokosch, H.U., Dudeck, J., Junghans, G., Marquardt, K., Sebald, Michel, A.: WING - Entering a New Phase of Electronic Data Processing at the Gießen University Hospital. Methods of Information in Medicine 1991, 30:289-298
2. Michel, A., Dieffenbach, M., Reisacher, A., Wiezcorek, D., Qiu, D., Dudeck, J.: MOVING A HOSPITAL INFORMATION SYSTEM TOWARDS A CLIENT SERVER ARCHITECTURE: in R.A. Greenes, H.E.Peterson, D.J. Protti (eds.): PROCEEDINGS OF THE EIGHTH WORLD CONGRESS ON MEDICAL INFORMATICS MEDINFO 95, NORTH-HOLLAND 1995
3. Thomas A. Oniki, M.S./Tery P. Clemmer, M.D./ Reed M. Gardner, Ph.D./ Kyle V. Johnson: Representative Charting of Vital Signs in an Intensive Care Unit: in Proceedings of the 18th. Symposium on Computer Applications in Medical Care, Washington 1994